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The Iron Curtain Effect in the Ultraviolet Spectra of Dwarf Novae Z Cha and OY Car

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We model the ultraviolet spectra of the quiescent dwarf novae Z Cha and OY Car, obtained in 1986 with the SWP camera of the *International Ultraviolet Explorer*, on the assumption that the flux is due to the central white dwarf seen through a haze of absorbing material. This material is optically thin in the continuum but thick in the lines of many atomic species, chiefly of iron-peak elements. These *IUE* observations are long exposures covering several orbits, and so they do not unambiguously refer to the white dwarf alone. This differs from the 1991 observation of OY Car's white dwarf by the Faint Object Spectrograph on *HST*, which was made using time-tagged eclipse spectrophotometry as discussed in Horne *et al.* (1994). The *HST* data also have the advantage of a photon counting detector. Nevertheless, there is interest in using the *IUE* data to observe the so-called "Iron Curtain" of OY Car at a different epoch, and to extend the study of the Iron Curtain to another dwarf nova in quiescence, Z Cha.

Results in terms of multiple-parameter fits for the white dwarf temperature and solid angle, and the column density, temperature, number density, and turbulent broadening of the Iron Curtain of each star, are discussed. An attempt is made to be consistent with the optical photometry of the white dwarfs, as determined by Wood *et al.* (1986, 1989).

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1. INTRODUCTION

The dwarf novae Z Chamaeleontis and OY Carinae are both eclipsing systems. The light curve in each case shows distinct eclipses for both the white dwarf primary star and the "bright spot" at the outer rim of the accretion disk. In the mid-1980's, high-speed photometric studies of these systems in visible light provided estimates for the mass, radius, and temperature of the white dwarfs, as well as maps of the surface brightness of the accretion disks (Wood et al. 1986, Wood et al. 1989).

Based on these studies, it was expected that in the ultraviolet, the quiescent spectrum would be overwhelmingly dominated by light from the white dwarf alone.

Low dispersion *IUE* observations of Z Cha and OY Car in quiescence were obtained in 1986 May to confirm this prediction and provide a better estimate of the white dwarf temperatures. The observations were carried out by R. Wade, G. Berriman, and G. Williger, using both the Goddard and Vilspa tracking stations. "Short" LWR (reduced voltage) and longer SWP spectra were obtained. The SWP exposure times are 13.0 hours for Z Cha (SWP 28262, 7.3 orbits) and 14.5 hours for OY Car (SWP 28263, 9.6 orbits). The data were extracted with IUESIPS, then the line-by-line files were reprocessed using the GEX (gaussian extraction) routine at the Goddard RDAF.

2. THE IRON CURTAIN

The SWP spectra looked more like A stars than white dwarfs. Preliminary attempts to fit them with solar abundance models (in collaboration with D. O'Neal) were abandoned when S. Shore pointed out the similarity of the absorption line pattern to his models of "circumstellar smog" (Shore 1992), that is, a stellar photosphere viewed through warm gas that is optically thin in the continuum but strongly absorbing in lines of iron-peak elements, hence the alternate name "iron curtain."

About the same time, K. Horne et al. (1994) reached a similar conclusion about a spectrum of the white dwarf in OY Car, obtained with the FOS aboard *HST*. Horne et al. used an implementation of the iron curtain contained in I. Hubeny's synthetic spectrum program SYNSPEC, and we have adopted the same program for work on the *IUE* spectra presented here.

The modeling assumes a photospheric spectrum of a white dwarf with solar abundances (modeled using TLUSTY, Hubeny 1988), viewed through a uniform slab (or curtain) of solar abundance gas in LTE. The model parameters for the white dwarf are $T_{\rm eff}$ and $\log g$, along with a solid-angle scaling factor. For the curtain, the parameters are $T_{\rm cur}$, $n_{\rm e}$, $v_{\rm turb}$, and $N_{\rm H}$, being respectively the gas temperature, electron density, turbulent broadening parameter (in km s^{-1}), and total hydrogen column density.

Further discussion of the model is given in Horne et al. (1994). One improvement over Horne et al. is that the white dwarf models now incorporate the hydrogen quasi-molecular absorption (Allard & Koester 1992).

3. PRELIMINARY RESULTS

An optimization routine finds a model that best fits the observed *IUE* spectrum, which is binned to 5 Å to reduce noise. (The region 1538–1557 Å containing the C IV emission line is not included in the fit.)

Figure 1 shows for each star the *IUE* spectrum and the best-fitting model. The data and model are smoothed. Agreement is satisfactory in view of the noisy nature of the data, and the omission from the model of emission lines, etc.

Table 1 presents preliminary best-fit parameters for the (white dwarf + curtain) model of the SWP spectra of Z Cha and OY Car. The Horne et al. results for OY Car, from FOS data (epoch 1991 December), are shown for comparison. We emphasize that additional work is required to establish definitive best-fit parameters, including attention to calibration issues, binning and smoothing choices, error estimates for the parameters, etc. The parameters n_e and N_H are probably good to a factor of two only, depending *inter alia* on whether the white dwarf temperature is "anchored" by consideration of the optical flux from the white dwarf as measured by Wood et al.

Comparing the *IUE* and *HST* results for OY Car, we find agreement at the factor of two level, suggesting that no large change in the properties of the absorbing curtain has been detected. Comparing the *IUE* results for OY Car and Z Cha, we find a significantly weaker absorbing curtain in the line of sight to Z Cha (about a factor of four), with somewhat reduced temperature but a similar high turbulent broadening parameter.

4. DISCUSSION

To illustrate the effect of the iron curtain on the spectrum, Figure 2 shows for each star the "bare" solar-composition white dwarf and the same white dwarf viewed through the absorbing curtain. The extra absorption varies considerably with wavelength, being especially strong near 1400 Å and in the 1600-1750 Å region.

Armed with this insight, one can examine the entire series of *IUE* spectra of Z Cha (usually taken during outbursts) to assess whether the absorbing curtain is variable. Inspection of the figures in La Dous 1990, which mainly refer to a single outburst in 1987 April, show large variations in the strength of the "dip" at ~1650 Å. (We are grateful to E.L. Robinson for bringing these spectra to our attention.) The curtain effect, if responsible for these variations, can clearly be stronger than we observe in our quiescent spectrum of Z Cha. The interpretation of outburst spectra to derive properties of the curtain will be less clear, however, since the disk with all its complexities will dominate the UV spectrum.

The estimates of white dwarf photospheric temperature taking the iron curtain effect into account are higher than the estimates of Wood et al., which were based on visual brightness temperatures and colors. This may reflect a true change in the photosphere of the white dwarf, since the Wood et al. papers refer to an epoch different from the *IUE* observations. Suggestions of a cooling of the white dwarf in OY Car have been found by Cheng et al. (1994) using FOS data, where following a superoutburst, the white dwarf apparently cooled from 20100 K to 17600 K with a time constant of 46 days. Our preliminary

T_{eff} for OY Car is within the range found by Cheng et al.

Note that, while the visible and FOS data can be used to isolate the spectrum of the white dwarf alone using the eclipses, the *IUE* data are averages over several orbits and may refer to light that has a more complex origin than a simple white dwarf photosphere. Additionally, there are remaining calibration uncertainties in the *IUE* data, as well as possible deficiencies in either the visible photometry model or the *IUE* model (e.g. a non-solar Si abundance for the white dwarf has been suggested by Cheng et al.) Thus the apparent differences in white dwarf temperature between Wood et al. and the present work (for both stars) may be in part real, due to cooling between outbursts, and in part spurious.

5. FURTHER WORK

The iron curtain model shows strong absorption in the 2300–2600 Å band, so it will be of interest to include the LWR *IUE* spectra in the analysis. Further wavelength coverage will allow a better estimate of the gas temperature in the iron curtain, since additional multiplets of the iron-peak ions will be brought into play. Refinement of the gas temperature will in turn allow more trustworthy estimates of the other model parameters to be made, including the white dwarf T_{eff}.

In addition, spectra of other quiescent dwarf novae (eclipsing and non-eclipsing) can be studied for signs of the iron curtain. Such studies can place constraints on the ubiquity of circumstellar (but not coplanar) gas in dwarf nova systems, and perhaps allow a determination of its location within the binary system.

References

Allard, N.F., & Koester, D., 1992, A&A, **258**, 464.

Cheng, F.H., Marsh, T.R., Horne, K.,& Hubeny, I., 1994, in "Evolution of X-ray Binaries" (Maryland Conference, October 1993), in press and updated MS.

Horne, K., Marsh, T.R., Cheng, F.H., Hubeny, I. & Lanz, T. 1994, ApJ **426**, 294.

Hubeny, I., 1988, Computer Phys. Comm., **52**, 103.

La Dous, C., 1990, Space Sci. Rev., **52**, 203.

Shore, S. N. 1992, in *Nonisotropic and Variable Outflows From Stars*, ed. L. Drissen, C. Leitherer, & A. Nota, (ASP Conf. Ser. 22), 342.

Wood, J., Horne, K., Berriman, G., Wade, R.A., O'Donoghue, D. & Warner, B., 1986, MNRAS **219**, 629.

Wood, J., Horne, K., Berriman, G., & Wade, R.A., 1989, ApJ **341**, 974.

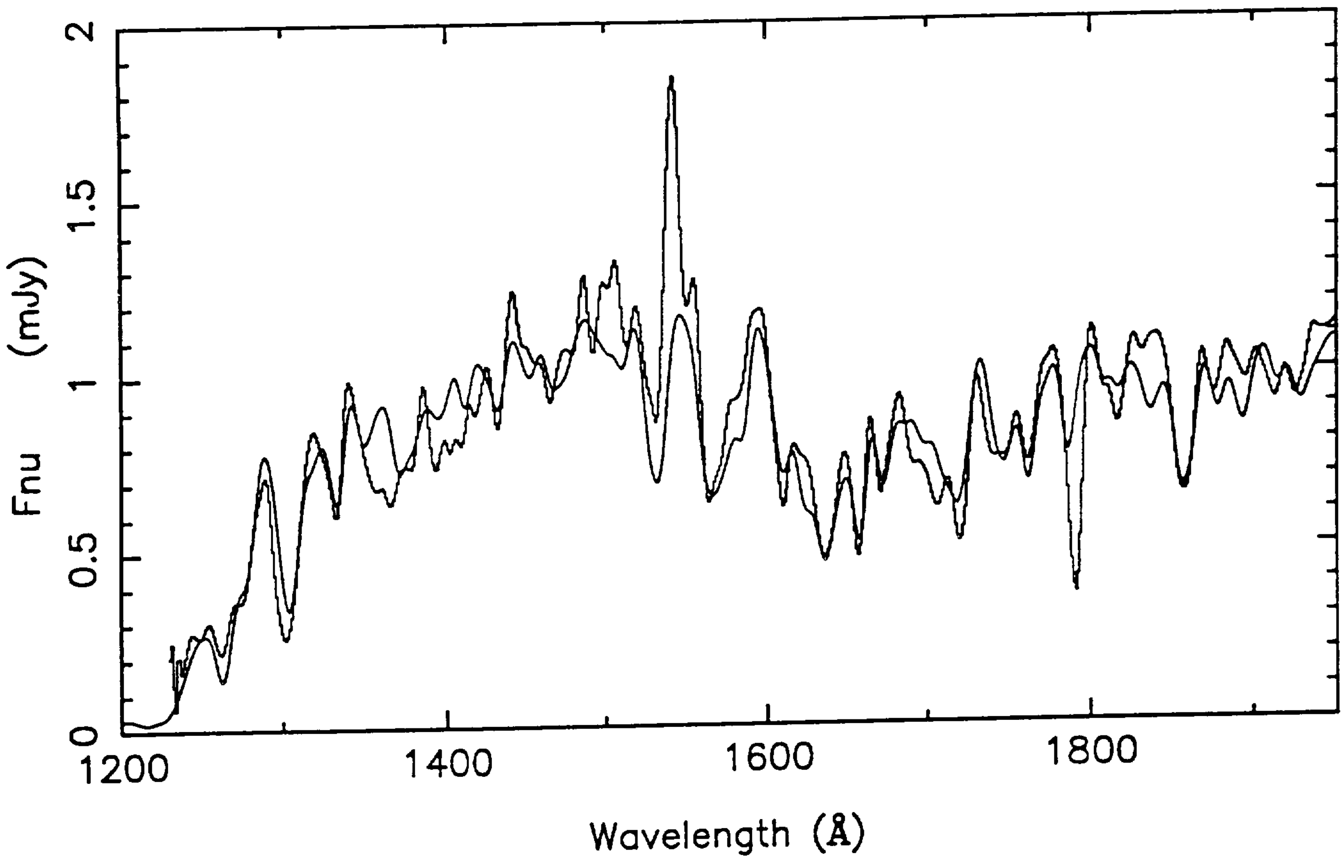
Table 1

Model Parameters

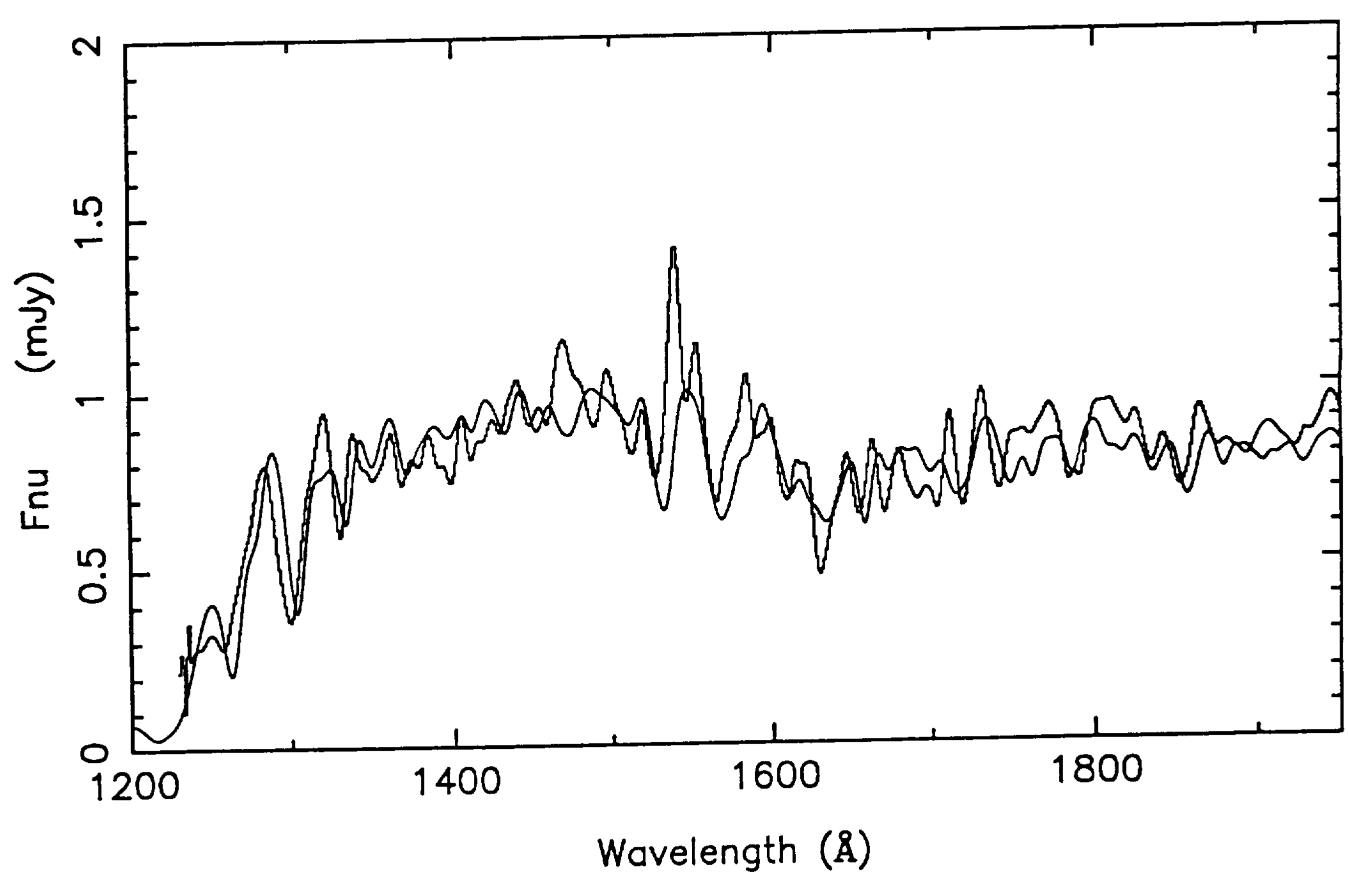
	Z Cha (IUE)	OY Car (IUE)	OY Car (FOS)[1]
$T_{\rm eff}$ (K)	21,000	19,000	16,500
$\log g$ (assumed)	8.00	8.00	8.00
$T_{\rm curtain}$ (K)	8200	9600	9900
$\log n_{\rm e}$ (cm^3)	11.7	12.5	12.9
$v_{\rm turb}$ (km s^{-1})	50	66	58
$\log N_{\rm H}$ (cm^{-2})	21.0	21.7	22.1
$\Delta R/R_{\rm wd}$ (note 2)	2.5	1.9	0.85
d. o. f. (note 3)	153	154	778
χ^2_ν (note 4)	0.95	1.44	4.1

Notes. (1) FOS model from Horne et al. 1994. (2) ΔR is the geometrical thickness of the absorbing slab, corresponding to $N_{\rm H}$. (3) Degrees of freedom. The IUE data were binned into 5 Å intervals. (4) The IUE data intervals have been assumed to carry equal error bars of 0.1 mJy. Thus the χ^2_ν values shown for IUE should not be used to interpret goodness of fit, but merely to indicate r.m.s. residuals.

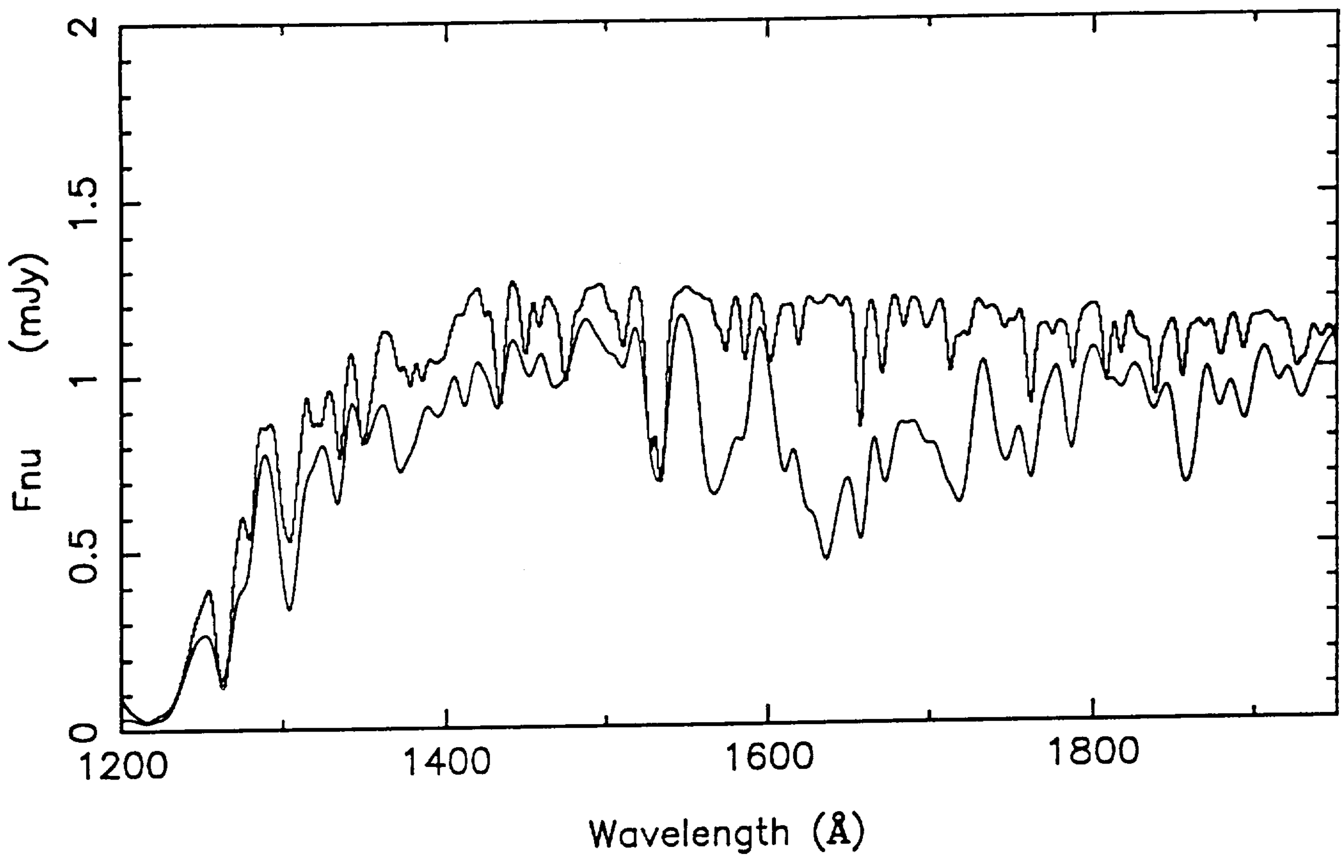
OY Car: Data and Best Model



Z Cha: Data and Best Model



OY Car's White Dwarf: Bare and "Draped"



Z Cha's White Dwarf: Bare and "Draped"